Dynamic Modeling of Marine Bioluminescence and Night Time Leaving Radiance

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LONG-TERM GOALS

The long-term objective is to contribute to the development of the components of limited area, open boundary, coastal nowcast/forecast systems that will resolve the time and length scales of the relevant physical-biological dynamics in shallow coastal environments.

OBJECTIVES

Our objectives are to develop the methodology for bioluminescence potential and bioluminescence leaving radiance predictions on scales to 1-5 days, and to understand the coupled bio-optical and physical processes in the coastal zone that governs the variability and predictability of bioluminescence.

APPROACH

Approach is based on joint studies of the marine bioluminescence potential (BP) and Inherent Optical Properties (IOPs) over relevant time and space scales, combining recent advances in the bioluminescence research: a novel approach for distinguishing relative abundances of planktonic dinoflagellates and zooplankton (Moline et al., 2009), modeling of nighttime leaving radiance and bioluminescence inversion (Moline et al., 2007 and Oliver et al., 2007) and development of a methodology for short-term bioluminescence predictions (Shulman et al., 2003 and 2005). The proposed research is being significantly leveraged by the interdisciplinary and multi-institutional modeling and field efforts of the NRL BIOSPACE and MURI ESPRESSO projects. Bio-optical, physical observations from the following field programs are being used in this study: AOSN I and II (Moline, 2007 and 2009, Shulman et al., 2003, 2005, 2009); bioluminescence observations from

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14. ABSTRACT
The long-term objective is to contribute to the development of the components of limited area, open boundary, coastal nowcast/forecast systems that will resolve the time and length scales of the relevant physical-biological dynamics in shallow coastal environments

15. SUBJECT TERMS

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Monterey Bay surveys conducted by Dr. Haddock (Augusts of 2000, 2002, Decembers of 2002 and 2003 and March of 2004); NRL BIOSPACE-ESPRESSO May-June of 2008 experiment; NRL BIOSPACE planned experiment in October 2010.

WORK COMPLETED

After a 2-day project kickoff meeting in MS with the participants of the project, we evaluated the available datasets and developed a strategy to both integrate the bioluminescence and optical fields into the modeling effort. We conducted an ensemble of BP intensity simulations for the 10-18th of August 2003 when BL observations from AUVs Remus (Cal Poly) and DORADO (MBARI) are available. Ensemble of model BL simulations is created by varying physical conditions. Evaluation of the model predictions is underway.

Based on the coupled bio-optical, physical data assimilating West Coast Modeling Prediction System (http://www7320.nrlssc.navy.mil/ccsnrt), we conducted a number of physical, bio-optical simulations for the time frame of 10-18th of August 2003. The system includes a hierarchy of different resolution NCOM (Navy Coastal Ocean Model) -based data assimilating models in the Pacific Ocean. This system provides large-scale, basin-scale, and small-scale views on physical, and bio-optical conditions in the Monterey Bay (Shulman et al., 2004, 2007). The Inherent Optical Properties (total absorption, absorption due to phytoplankton, backscattering) were estimated for 9 bands. Evaluation of IOPs predictions and comparisons with available satellite-derived and in situ data are underway.
In the next step of the project, we will be integrating the BP with the optics to predict leaving radiance. In order to do this, we have converted the total BP flash obtained from observations to a spectral signal, based on previous laboratory studies (Moline et al., 2007). This allows for spectral radiative transfer of BP potential to the surface. This will be done both in Hydrolight and by empirical techniques.

We are also incorporating the inherent diel rhythms of BP intensity in the model, with BP intensity greatest at night and lowest during the day. Based on a 4-year time series of BP measurements from the Cal Poly pier and AUV REMUS data, we have been creating time dependent, spectral response of BP to the PAR and the Sun position. This function will be a time dependent quenching function for future model runs to account for the diel periodicity of BP.

RESULTS

Preliminary predictions from the bioluminescence model and the coupled bio-optical, physical data assimilating West Coast Modeling Prediction System have been evaluated. As it was stated in the approach, the Inherent Optical Properties (IOPs) from the system are being used in estimation and modeling of the night time leaving radiance due to BP.

Distributions of the surface properties during the bioluminescence modelling experiments are shown on Figure 1. HF radar derived surface currents, averaged over three days of upwelling (Figure 1a, August 15-17 of 2003), show the development of a strong, wide southward-flowing jet at the surface, which extends up to 150m depth (not shown here). The jet separates a pair of cyclonic (inside of the Bay) and anticyclonic (outside of the Bay) circulations. The southward flowing jet and cyclonic-anticyclonic circulations are also well represented in the satellite-derived SST and Chl images from MODIS-AQUA satellite (Figure 1, b and c). With the intensification of the upwelling, cold upwelled, nutrient rich, low phytoplankton water masses are advected by the strong, wide southward jet along the entrance to the Bay, and by the cyclonic circulation into the Bay and the anticyclonic circulation offshore. Warmer and less productive water masses are in the center of the anticyclonic circulation

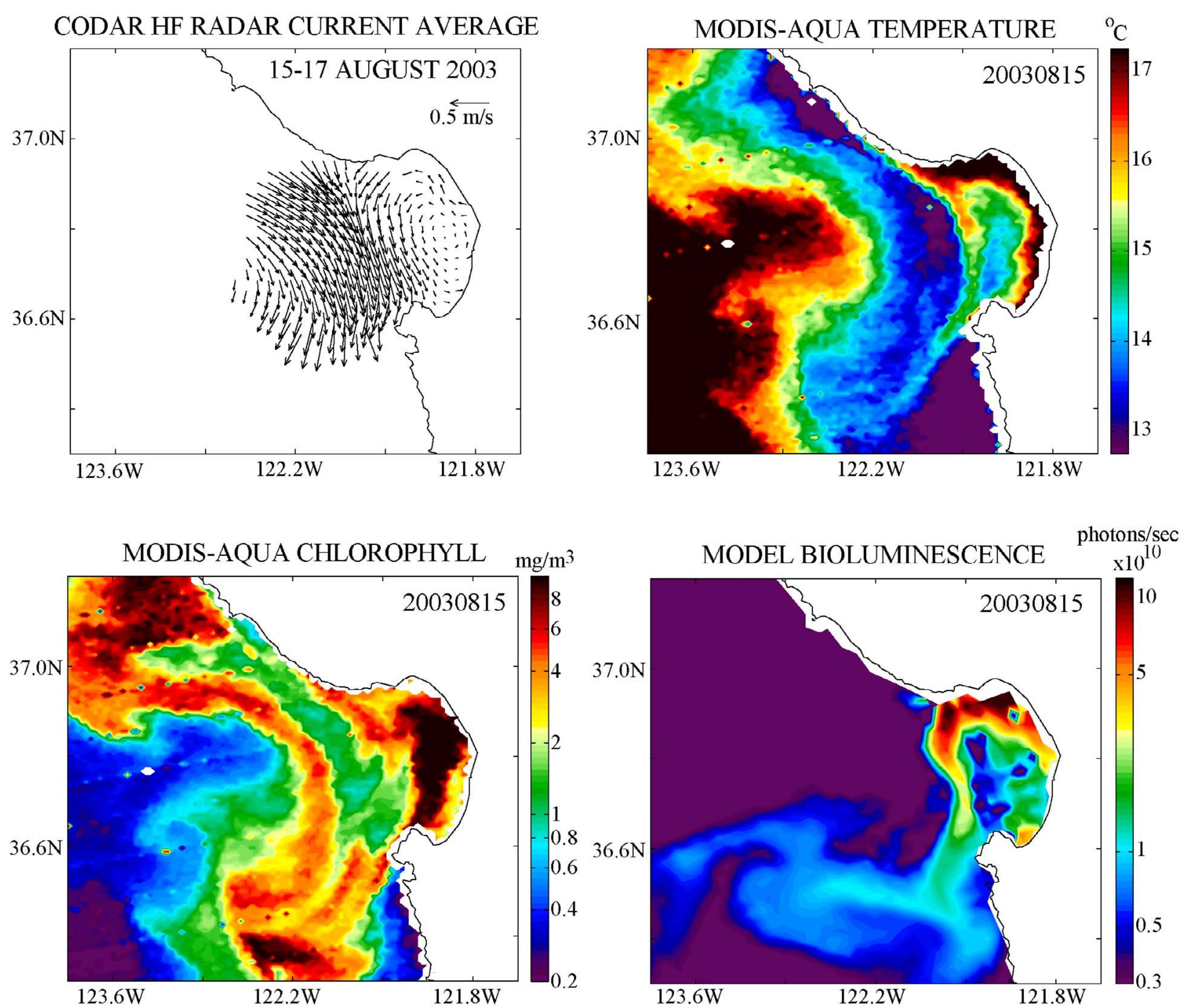

Figure 1. (A) HF radar surface currents averaged over three days August 15th -17th of 2003, (B) Satellite derived MODIS-AQUA SST image for August 15th of 2003, (C) Satellite derived MODIS-AQUA Chlorophyll image for August 15th of 2003; (D) Model-predicted surface distribution of the bioluminescence potential (BP) for August 15th of 2003.

offshore and the relatively more productive water masses at the eastern flank of the anticyclonic circulation (western side of the southward jet). In the Bay, there are water masses with warmer and higher Chl values along the coast and the edges of cyclonic circulation in the Bay (especially in the northern area of the Bay called upwelling shadow area). Figure 1 also shows surface distribution of the modeled bioluminescence based on the approach outlined in Shulman et al, 2003 and 2005. The bioluminescence model was initialized on August 14th of 2003 using BP data from AUVs REMUS and DORADO (Moline et al, 2009). Figure 1d shows BP surface forecast on August 15th (one day after the model initialization). The modeled surface distribution of BP on August 15th is in good agreement with the described above bio-optical, physical conditions. BP intensity is highest along the edges of the northern flank of the cyclonic eddy in the Bay, with highest values in the northern part of the Bay. Also, BP is spread along the entrance to the bay following the southward flowing jet.

Figure 2 shows observed subsurface properties during the modeling (along the REMUS track on August 15th, Figure 2, top insert). Chlorophyll (Figure 2a) and backscatter (Figure 2b) distributions show relatively high values in the center of the Bay. High presence of the phytoplankton in the center of the Bay might be a continuation of the Chl from the northern coast of the Bay advected by the strong southward jet. This is supported by the Chl and SST images (Figure 1a and b) showing advection of the water masses from the north to the center of the Bay. Because of the weak BP intensity signal in the center of the Bay (Figure 2c), mostly non-bioluminescent phytoplankton (not dinoflagellates) were advected from the north to the center of the Bay. High values of backscatter do also suggest that these are cells smaller than diatoms.

The modeled subsurface BP distributions (Figure 2d) show some similarities and differences with the observed BP (Figure 2c) on August 15th. For example, high values of modeled as well as observed BP are confined to the northern/ north-east coast of the Bay. At the same time, the modeled BP shows high values at the center of the Bay, which are not seen in the observations. In the bioluminescence model (Shulman et al., 2003 and 2005), there is no modeling of dinoflagellate behavior and biological interactions influencing the dinoflagellate. After initialization with BP observations, only advection and diffusion controls the BP distributions. According to Figures 1d and 2d, the modeled BP intensity was advected by southward jet to the center in the Bay, what is not shown in BP observations (Figure 2c). Results presented here indicate the need for improvement of the BP model by incorporating sources and sink terms representing ecological interactions controlling the bioluminescence.

Figure 2 shows also modeled distributions of diatoms (Figure 2e) and small phytoplankton (Figure 2f) on August 15th from the coupled bio-optical, physical data assimilating West Coast Modeling Prediction System (http://www7320.nrlssc.navy.mil/ccsnrt). Shulman et al., 2004, 2007). Figure 2 show high concentration of small phytoplankton and low values of diatoms in the center of the Bay. This is in agreement with discussed above observations supporting the hypothesis that high values of Chl and backscatter in the center of the Bay are a result of the advection of the small phytoplankton cells from the northern part of the Bay.

IMPACT/APPLICATIONS

Prediction of the location, timing and intensity of bioluminescence potential is critical for numerous naval operations including preventing detection of covert operations involving submarines, Swimmer Delivery Vehicles and AUVs, as well as in aiding detection of enemy incursions. At present, the Navy does not have capability to forecast BL potential and night time water leaving radiance. The proposed research aims to develop a methodology for bioluminescence potential and bioluminescence leaving radiance predictions on scales to 1-5 days.

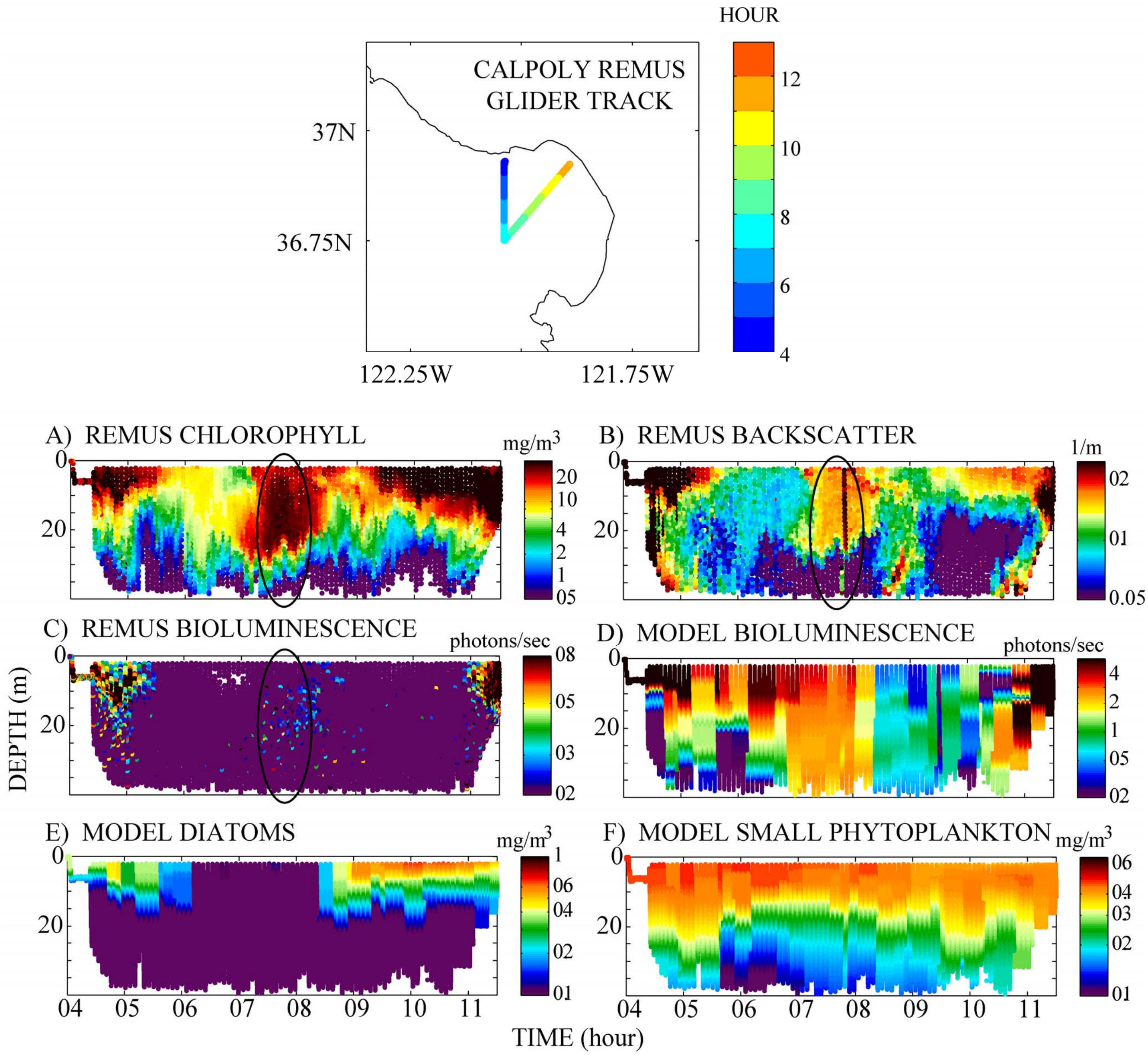

Figure 2. Observed and modeled subsurface properties along the AUV REMUS track (top panel) on August 15th of 2003. Observed subsurface distributions of chlorophyll (A), backscatter at 880nm (B) and bioluminescence potential (BP) (C). Model-predicted subsurface distributions of BP (D), diatoms (E) and small phytoplankton (F).

TRANSITIONS

This is a new effort begun in January of 2009

RELATED PROJECTS

NRL, RO " Bio-Optical Studies of Predictability and Assimilation for the Coastal Environment (BIOSPACE)" (PI: I. Shulman)

Shulman is PI of the NRL project with objectives to improve understanding of the variability and predictability of the underwater light and bio-optical, physical properties on time scales of 1 to 5 days. NRL coupled models and predictions of physical bio-optical properties (including IOPs and BP) are used in our project.

The Multidisciplinary University Research Initiative (MURI) project "Rapid Environmental Assessment Using an Integrated Coastal Ocean Observation-Modeling System (ESPRESSO)" (PIs: O. Schofield, S. Glenn, J.Wilkin, G. Gawarkiewicz, R. He, D. McGillicuddy, K. Fennel, M. Moline).

Objectives of the MURI project are focused on the development of a data assimilative physical-optical modeling-observation system capable of improving predictive skill for forecasting ocean color and improving physical models by using ocean color. M. Moline is Co-PI of the project, and NRL BIOSPACE and MURI project have similar objectives and there are ongoing collaborations between projects.

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PUBLICATIONS

This is a new effort begun in January of 2009.

HONORS/AWARDS/PRIZES

Dr. Shulman is recipient of the NRL 41st Alan Berman Publication Award.